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## Unique Mud Banks, Kerala, Southwest India<sup>1</sup>

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**Abstract** The "mud banks" of Kerala (southwest India), a potential modern analogue of an ancient hydrocarbon-generating environment, are in nearshore shallow water about 10 m deep. Individual banks extend over an area of 25 sq km or more. They are characterized by rapidly accumulating fine-grained silty clay sediments, high organic matter, oxygen-deficient bottom waters, and dense mud suspensions. The muds are thixotropic, and the sedimentary environment suggests conditions suitable for gas generation within the sediments. It is proposed tentatively that thixotropic and gas-generation properties of the sediments, with the waves, keep the mud in suspension and result in the spectacular wave-damping property of the mud banks.

### INTRODUCTION

The problem of origin and accumulation of hydrocarbons continues to remain enigmatic. Much attention currently is directed to the location of offshore areas for petroleum exploration in view of the limited resources expected onshore. Of value to such offshore-exploration ventures are regions on the coast possessing oil-bearing and oil-producing geologic formations which may be classed as first-order indicators, and associations such as sufficient thickness of sediments with or

without coal-bearing formations which may be classed as second-order indicators.

Modern analogues of ancient hydrocarbon-generating environments have been documented and some of them have been subject to detailed investigations (Weeks, 1958; Emery, 1960; Hedberg, 1964, 1970). The purpose of this paper is to document an additional example in what has been termed "mud banks" off the Kerala coast, on the southwest coast of India (Fig. 1).

The deposition of mud along the beaches of Kerala, at localities in a belt 272 km long between Kozhikode (Calicut) in the north and Quilon in

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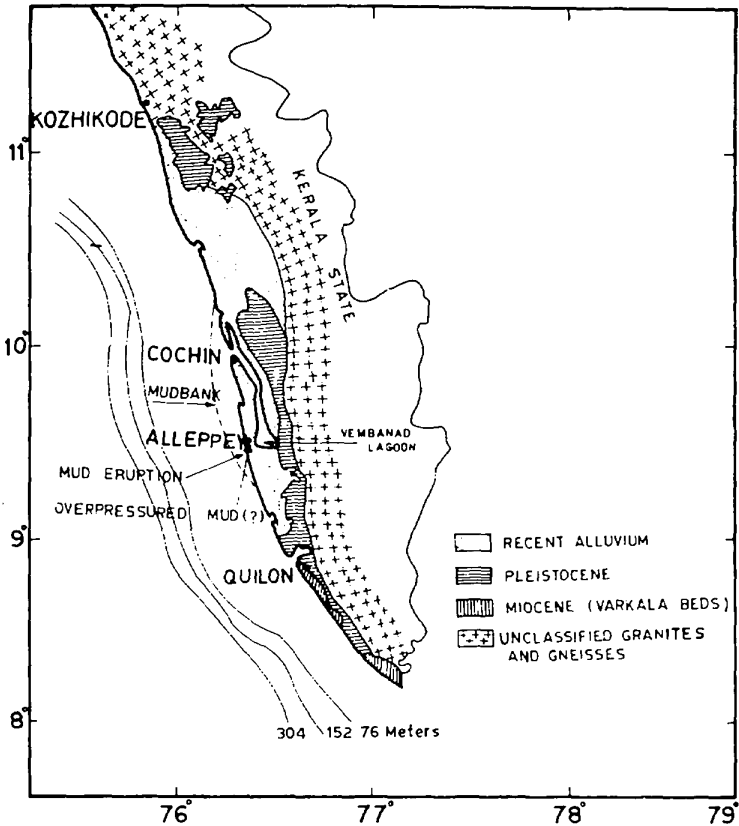


FIG. 1.—Map showing location of two major mud banks. Dashed line encloses approximate area of occurrence. Note relation of mud banks to Vembanad Lagoon and location of mud eruption and overpressured muds at Alleppey. (Geology after India Geol. Survey, 1962.)

the south (Fig. 1) is a recurring though infrequent feature. The deposition of mud commonly takes place during the southwest monsoon season (June to September) and during the passage of storms in other seasons. The rather sudden deposition (over a period of a few days) and the prevalence of dense mud suspensions in the littoral waters adjacent to the Kozhikode-Quilon coast have been referred to collectively as "mud banks" by Bristow (1938).

#### PHYSICAL CHARACTERISTICS OF MUD BANK

Unfortunately no definite guidelines for demarcating the boundary and estimating the areal dimensions of the banks are available. The most common criterion is the visual estimation of the line of breakers or surf on the seaward edge of the banks (Fig. 2). In this context a noteworthy fea-

ture is the remarkable damping effect of the mud suspension on the incident waves. It was the extraordinary calming effect that the banks exert in the roughest weather that led to their recognition as a safe anchorage as long ago as 1723 (Bristow, 1938). This damping property is used frequently by the present coastal fishing fleet. Using this seaward breaker line and the smooth water areas as criteria, Gopinathan and Qasim (1974) reported the banks to extend about 6 km from shore to a water depth of about 7 to 10 m and about 4 km alongshore. Two banks appear more frequently, one at Alleppey and the other at Cochin (Fig. 1). The mud banks wax and wane and tend to migrate laterally along the coast under the influence of changing coastal circulation. The shore adjoining the banks commonly is protected from erosion because of the buffering effect the banks

have on the waves which otherwise would have expended their energy on the beach.

#### OCEANOGRAPHIC FEATURES

The southwest coast of India is a region of upwelling (Banse, 1959), the influence of which is felt in the nearshore and estuarine regions by the intrusion of upwelling waters poor in oxygen (Sankaranarayanan and Qasim, 1969). Damodaran (1973) studied in detail the hydrography of the mud bank off Cochin (Narakal). He reported that the temperature in the mud-bank region reaches a minimum of about 27°C in July-August (monsoon season) from a maximum of about 30°C in April. Salinity values show a similar seasonal trend, with a minimum in July-August of 15-20 parts per thousand and a maximum of 34.5 parts per thousand in April. Both temperature and salinity are related strongly to the monsoon rains. Dissolved oxygen in the bottom waters is low during May and June and a marked decline in the value occurs during July and August. The decrease in oxygen in coastal bottom waters has been attributed partly to the low-oxygen content of the upwelling waters and partly to the oxidation of organic matter in the banks.

#### GRAIN SIZE AND MINERALOGY OF MUDS

The grain size of the sediment constituting the mud banks and the mud flats falls in the silty-clay range. Nair et al (1966) reported that the dominant component is always clay (45 to 65 percent) with a secondary amount of silt, and a very small sand fraction. Water content is uncommonly high and ranges from 60 to 80 percent. Damodaran (1973) and Jacob and Qasim (1974) reported similar sediment characteristics from the different banks. The coarse fraction of the sediments consists of weathered muscovite, biotite, and iron-stained quartz with much plant and wood material. Skeletal material in the coarse fraction is conspicuously absent.

X-ray diffraction analyses of the mud showed that poorly crystalline kaolinite was the most abundant (60 to 65 percent) with 15 to 20 percent montmorillonite (saponite) and 15 to 20 percent illite, and trace quantities of chlorite, gypsum, and quartz (Nair and Murthy, 1968). The sediments contain 5 to 8 percent of organic matter, the values being higher than in the sediments outside the bank.

#### RELATION OF MUD BANKS TO MUD VOLCANOES

According to Hedberg (1974), "the term mud volcano is generally applied to a more or less violent eruption or surface extrusion of watery mud or clay which almost invariably is accompanied by methane gas and which commonly tends to

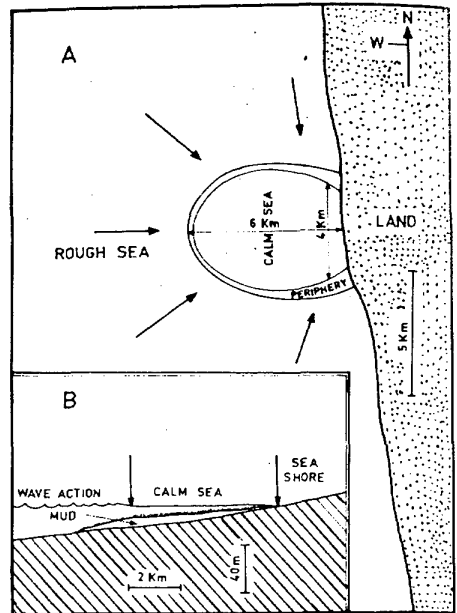


FIG. 2—A, Diagrammatic sketch of mud bank. Periphery indicates seaward breaker zone enclosing mud bank. B, Cross section of mud bank. (Adapted from Jacob and Qasim, 1974.)

build up a solid mud or clay deposit around its orifice which may have a conical shape or a volcano-like shape." He further pointed out that mud volcanoes commonly appear to be related to lines of fracture, faulting, or folding and that there appears to be a close interrelation between undercompacted muds or shale bodies, mud or shale diapirs, mud lumps, and mud volcanoes.

In the context of the preceding statement, it would be interesting to enumerate similarities and dissimilarities of the Kerala mud banks to mud volcanoes and allied phenomena. But before that a brief review of the marine geology of the western continental shelf, especially the sediment distribution, may be helpful in placing the mud banks in proper perspective.

Study of the surficial sediments of the western continental shelf (Nair and Pylee, 1968) has shown that the shelf can be divided into two distinct sediment facies. The inner shelf from about 3 m water depth to about 65 m consists of silts and clays (clay 20 to 90 percent), high organic matter 2 to 6 percent, low calcium carbonate (less than 10 percent; Nair and Pylee, 1968; Murthy et al, 1969). Within this zone of terrigenous silts and clays are the mud banks. Seaward from 65 m to

the continental-shelf edge (depth variable between 90 and 130 m) representing the outer shelf, the sediments are relict sand-size carbonate material in the form of oolites, shells of mollusks, foraminifers, coral, and coralline algal debris (Nair, 1971). In terms of age, the inner-shelf silts and clays are of recent origin, whereas the outer shelf, carbonate sands, and rocks have been radiocarbon dated as late Pleistocene (Nair, 1974). Against the background of shelf-sediment distribution, one may proceed to evaluate the following aspects of the mud banks.

#### DISTRIBUTION OF MUD BANKS

The mud banks are confined to the tectonically stable Kerala coast between Kozhikode and Quilon. This stretch of coast is backed by recent coastal alluvium and, more significantly, by the backwaters (lagoons) of Kerala (Fig. 3). The strong circumstantial evidence cannot be overemphasized and points to a causal relation between the two and hence to the speculation that the hydraulic head developed in the lagoon during the southwest monsoon (rainfall about 5,000 mm per annum) results in submarine seepages in the offshore areas which keep the mud in suspension. That such a speculation is unfounded arises from the fact that banks are present even during the nonmonsoon seasons (Gopinathan and Qasim, 1974).

#### COASTAL FORMATIONS

A system of barrier beaches separates the backwaters from the sea. Recent alluvium extends from the shores of the lagoons eastward for 16 to 24 km inland (Fig. 1). On the south, near Quilon, the lower Miocene Verkala strata are exposed as cliffs near the beach. They consist of a laterite capping, followed by sandy clays containing lignite and pyrite (King, 1882; Poulouse and Narayanaswamy, 1968). Rao (1968) reported radiocarbon ages of more than 40,000 years for two samples of the lignite. The two dates are inconclusive, as they represent only the limit of the radiocarbon-dating technique. A generally youthful age, however, is suggested by the freshness of the wood in the lignite but becomes difficult to reconcile with the early Miocene age derived from paleontologic and lithologic factors (Krishnan, 1960).

#### GASEOUS DISCHARGE AND ASSOCIATED PHENOMENON

No continued series of systematic observations of gas discharges ever has been made and, therefore, no satisfactory conclusions are possible. The observations to be cited are drawn entirely from Bristow (1938). Many of them should be accepted

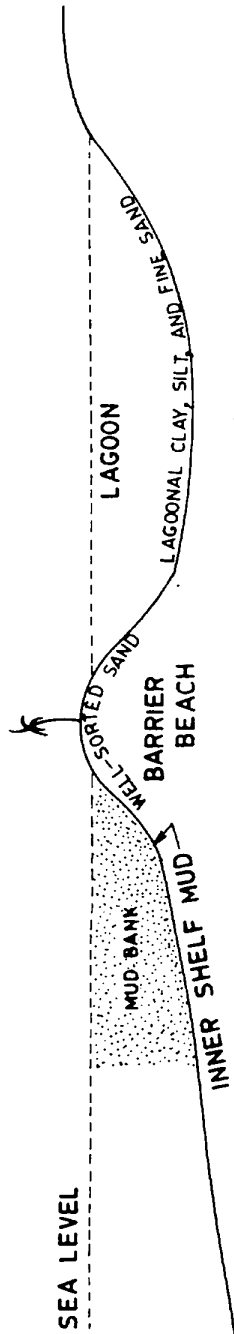


FIG. 3.—Geomorphologic relation between mud bank, barrier beach (at Alleppey), and lagoon (Vembanad Lagoon).

with qualification and all of them require corroboration.

Bristow (1938) compiled incidents of gaseous discharge in the mud bank proper and on the adjoining shore (barrier beach). His citation of the report of Hugh Crawford is reproduced here at length because of its informative value and vividness. Crawford, writing in 1860 to the British Resident at Trivandrum about the eruptions in the Alleppey mud bank, said that when the cones burst they throw up "immense quantities of soft soapy mud and blue mud of considerable consistency in the form of boulders with fresh water, debris of vegetable matter, decayed and in some instances green and fresh. These bubbles are not confined to the seaboard but are, I am inclined to think both more active and numerous in the bed of the roads with the Flag staff bearing ENE to the south until it bears N. E. by N or even south of that. About five years ago about 4 miles down the coast and from the beach out to sea for a mile and a half, the sea was nothing but liquid mud, the fish died and as these cones reared their heads above the surrounding mud they would occasionally turn over a dead porpoise and numerous other fish. The beach and the roads presented then a singular appearance, nothing to be seen but these miniature volcanoes, some silent, others active, perfect stillness all around the ships in the road as if in some dock, with a heavy sea breaking in 7 fathoms outside" (Bristow, 1938, v. 1, p. 73-74).

Other instances of eruption are reported during the monsoon and probably result from the release of entrapped gas by the pressure fluctuations of the short-period storm waves associated with the monsoon. No data are available on the nature of the gas but one tends to conclude that the gas in all probability is biogenic methane (marsh or swamp gas) which, as pointed out by Hedberg (1974), is a ubiquitous product of the accumulation of fine-grained organic matter in sediments. That the generation of gas is sufficient to cause overpressuring of the muds is suggested by the eruptions and the sudden sinking of its own accord (reported by Crawford) of the drill shaft to a depth of 80 ft (24 m) in the soft muddy stratum in a bore hole on the beach at Alleppey. Bore-hole data on the adjacent barrier beaches indicate the common presence of vegetable matter, wood, and lignite and other carbonaceous matter intercalated with sandstone and clay (Brown, 1938) and suggest that adequate raw material is present for the generation of methane.

#### THIXOTROPIC PROPERTIES OF MUD

Thixotropy is that property by which fine wet clay remains as an undisturbed mass in solid form

until, either as a result of a sudden shock or loss of an electrolyte, the clay suddenly becomes a flowing fluid (Kerr et al, 1970). The mud-bank sediments, as mentioned previously, are predominantly clay-sized (45 to 65 percent clay fraction), composed largely of kaolinite with secondary amounts of montmorillonite and illite. The thixotropic properties of these muds were studied by Keen (1938), specifically in relation to the damping effect the banks have on the waves. Keen determined the kinematic viscosities of 5- and 10-percent mud suspension in distilled water and 1/8- and 1/4-percent sodium chloride solutions and found that a 5-percent mud suspension, over a range of stresses, had a kinematic viscosity of 25 and that a 10-percent mud suspension had a kinematic viscosity of 58. He further reported a rapid increase in viscosity at low stresses, so much so that a 10-percent mud concentrate became comparable in effect with a sugar solution of 60 percent (kinematic viscosity about 450) which is a thick syrup. This behavior is typical of thixotropic muds and is the principal cause of damping.

An additional aspect of the thixotropic behavior of the clays is its role in keeping the mud in suspension. The sharp reduction in salinity during the monsoon, from about 34 parts per thousand to between 10 and 20 parts per thousand perhaps makes the solid or semisolid mud unstable and may be the triggering mechanism which converts the mud from the semisolid state to a liquid one. This mechanism, coupled with the simultaneous action of waves (acting upon the bank) which disturb the mud and release pockets of entrapped gas, may be the cause for maintaining the mud in suspension.

The enumerated features of the mud banks suggest that they are atypical phenomena. No obvious volcanic activity in the strict sense of the term is associated with the Kerala banks, unlike those of Burma (Krishnan, 1960) and off New Zealand (Ridd, 1970) which are in seismically unstable areas.

In conclusion, the characteristics of the mud banks—accumulation of fine-grained sediments, high organic matter, oxygen-deficient bottom waters, with the possible generation of methane gas in the sediments and suggestions of overpressuring in the adjoining onshore formations—are illustrative of an environment in which a complex interplay of diverse processes takes place. For the petroleum geologist, the mud banks present an additional modern analogue of a natural hydrocarbon-generating system and acquire greater significance in view of the fact that Eremenko (1968) reported Tertiary sediment thickness of the order of 4,000 ft (1,212 m) on the continental shelf and slope off Kerala.

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Urania, 1925, to Laredo, 1975<sup>1</sup>EDGAR W. OWEN<sup>2</sup>

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The Wilcox Group (lower Eocene) in the United States Gulf Coast reached its 50th year of productive history in 1975. It has furnished important reserves in several hundred oil and gas fields along a 600-mi stretch from Mississippi to Mexico. No single oil field has supplied as much as 100

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